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New Approaches for Difference Constraint Systems - Final Report (October 2010)

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Contents

1

1   Introduction

In this report we summarize our contributions over the period 2006-2010. The principal objective of our work is the design, development and analysis of fundamentally new techniques for the problem of solving conjunctions of difference constraints. This problem is well-known to be equivalent to the problem of checking whether a directed graph (network) with positive and negative weights on its edges has a negative cost cycle (NCCD). The NCCD problem finds applications in a number of different design domains such as Program Verification, Real-Time Scheduling and Operations Research. We have looked at several variants of the NCCD problem, including the lightest negative cycle problem, the Horn constraint problem and the Unit Two Variable Per Inequality constraint problem. Each of the specialized constraint classes Our work has resulted in numerous publications in respected journals and conferences.

2   Refereed Journal Publications (Cumulative)

In this section, we enumerate all the archival journal publications that arose as a result of AFOSR-supported research. The papers have been listed by domain.

2.1   Negative Cost Cycle Detection

[N1] N. Shankar and K. Subramani. On mechanically verifying the correctness of the Stressing Algorithm. *Science of Computer Programming (SCP)*. (**Accepted, In Press.**)

[N2] K. Subramani, C. Tauras and Kamesh Madduri. Space-Time Tradeoffs in Negative Cycle Detection - An empirical analysis of the Stressing Algorithm. *Applied Mathematics and Computation (AMC)*, **215** (10), pp. 3563-3575, Elsevier Science Publishers, 2010.

[N3] K. Subramani. Optimal Length Resoution Refutations of Difference Constraint Systems. *Journal of Automated Reasoning (JAR)*, **43** (2), pp. 121-137, pp. 121-137, Springer Science Publishers, 2009.

[N4] K. Subramani. A Zero-Space Algorithm for Negative Cost Cycle Detection in Networks. *Journal of Discrete Algorithms (JDA)*, **5** (3), pp. 408-421, Elsevier Science Publishers, 2007.

[N5] K. Subramani and J. Argentieri. Chain Programming over Difference Constraints. *Nordic Journal of Computing (NJC)*, **13** (4), pp. 309-327, Publishing Association of the Nordic Journal of Computing, 2006.

[N6] K. Subramani and D. Desovski. On Contrasting Vertex Contraction with Relaxation-based approaches for negative cost cycle detection. *Applied Mathematics and Computation (AMC)*, **173** (1), pp. 273-305, Elsevier Science Publishers, 2006.

2.2   Shortest path problems

[S1] K. Subramani and Kamesh Madduri. Two-Level Heaps: A new Priority Queue structure with applications to the Single Source Shortest Path problem. *Computing*. (**Accepted, In Press.**)

[S2] James B. Orlin, Kamesh Madduri, K. Subramani and M. Williamson. A Faster Algorithm for the Single Source Shortest Path Problem with Few Distinct Positive Lengths. *Journal of Discrete Algorithms (JDA)*, **8** (2), pp. 189-198, Elsevier Science Publishers, 2010.

[S3] K. Subramani and Kamesh Madduri. A Randomized, Queueless algorithm for Breadth-First Search. *International Journal of Computers and their Applications (IJCA)*, **15** (3), pp. 177-186, ISCA Press, 2008.

2.3   Randomized approaches to constraint solving

[R1] K. Subramani and X. Gu. Absorbing Random Walks and the NAE2SAT problem. *International Journal of Computer Mathematics (IJCM)*. (**Accepted, In Press.**)

[R2] K. Subramani. On Memoryless Provers and Insincere Verifiers. *Journal of Theoretical and Experimental Artificial Intelligence (JETAI)*, **21** (3), pp. 217-231, Taylor & Francis Publishers, 2009.

[R3] K. Subramani, Hong-Jian Lai and Xiaofeng Gu. Random Walks for Selected Boolean Implication and Equivalence Problems. *Acta Informatica*, **46** (2), pp. 155-168, Springer Science Publishers, 2009.

2.4   Sorting and Automata Theory

[SA1] K. Subramani, C. Tauras and David Owen. Fault Tolerant Sorting - Theoretical and Empirical analyses of the Randomized QuickMergesort algorithm. *Journal of Mathematical Modeling and Algorithms (JMMA)*, **7** (3), pp. 255-276, Springer Science Publishers, 2008.

[SA2] K. Subramani. Computing inversion pair cardinality through partition-based sorting. *Computing*, **83** (1), pp. 41-54, Springer Science Publishers, 2008.

[SA3] K. Subramani and C. Tauras. An Approximation Algorithm for State Minimization in 2-MDFAs. *Formal Aspects of Computing (FAC)*, **18** (4), pp. 421-431, Springer Science Publishers, 2006.

2.5   Real-Time Scheduling

[RT1] K. Subramani, Kiran Yellajyosula and A. Osman. Distributed Algorithms for Partially Clairvoyant Dispatchers. *Cluster Computing (CC)*, **11** (2), pp. 115-131, Springer Science Publishers, 2008.

[RT2] K. Subramani and Kiran Yellajyosula. On the Design and Implementation of a Shared Memory Dispatcher for Partially Clairvoyant Schedulers. *International Journal of Parallel Programming (IJPP)*, **36** (4), pp. 386-411, Springer Science Publishers, 2008.

[RT3] K. Subramani and D. Desovski. An empirical analysis of algorithms for Partially Clairvoyant Scheduling. *International Journal of Parallel, Emergent and Distributed Systems (IJPEDS)*, **22** (5), pp. 331-353, Taylor & Francis Publishers, 2007.

[RT4] K. Subramani. A polynomial time algorithm for Zero-Clairvoyant Scheduling. *Journal of Applied Logic (JAL)*, **5** (4), pp. 667-680, Elsevier Science Publishers, 2007.

[RT5] J. I. Rasmussen, Kim G. Larsen and K. Subramani. On using priced timed automata to achieve optimal scheduling. *Formal Methods in System Design (FMSD)*, **29** (1), pp. 97-114, Springer Science Publishers, 2006.

2.6   Simple and Quantified Constraint Solving

[C01] K. Subramani. On the Complexity of Selected Satisfiability and Equivalence Queries over Boolean Formulas and Inclusion Queries over Hulls. *Journal of Applied Mathematics and Decision Sciences (JAMDS)*, vol. **2009**, 18 pages, Hindawi Publishing Corporation, 2009.

[C02] Sanjit A. Seshia, K. Subramani and Randal E. Bryant. On Solving Boolean Combinations of UTVPI Constraints. *Journal on Satisfiability, Boolean Modeling and Computation (JSAT)*, **3** (1, 2), pp. 67-90, IOS Press, 2007.

[C03] K. Subramani. On a Decision Procedure for Quantified Linear Programs. *Annals of Mathematics and Artificial Intelligence (AMAI)*, **51** (1), pp. 55-77, Springer Science Publishers, 2007.

[C04] Hans Kleine Büning, K. Subramani, and Xishun Zhao. Boolean Functions as Models for Quantified Boolean Formulas. *Journal of Automated Reasoning (JAR)*, **39** (1), pp. 49-75, Springer Science Publishers, 2007.

3 Refereed Archival Conference Publications (Cumulative)

[C1] R. Chandarasekaran and K. Subramani. A combinatorial algorithm for Horn Programs. *Proceedings of the 20th International Symposium on Alogrithms and Computation (ISAAC)*, pp. 1114-1123, (Eds.) Yingfei Dong, Ding-Zhu Du and Oscar Ibarra, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 5878, Honolulu (Hawaii), December 2009.

[C2] K. Subramani and Kamesh Madduri. Two-level heaps: A new Priority Queue structure with applications to the Single Source Shortest Path problem. *Proceedings of the 3rd Annual International Conference on Combinatorial Optimization and Applications (COCOA)*, pp. 186-196, (Eds.) Ding-Zhu Du, Xiadong Hu and Panos M. Pardalos, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 5573, Yellow Mountains (China), June 2009.

[C3] K. Subramani and Kamesh Madduri. Accomplishing Approximate FCFS fairness without queues. *Proceedings of the 14th Annual International Conference on High Performance Computing (HiPC)*, pp. 540-551, (Eds.) Srinivas Aluru, et. al., *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 4873, Goa (India), December 2007.

[C4] K. Subramani. A randomized algorithm for BBCSPs in the Prover-Verifier Model. *Proceedings of the 4th International Colloquium on Theoretical Aspects of Computing (ICTAC)*, pp. 455-466 , (Eds.) Cliff Jones, Zhiming Liu and Jim Woodcock, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 4711, Macau SAR (China), September 2007.

[C5] K. Subramani and J. Argentieri. Analyzing Chain Programs over Difference Constraints. *Proceedings of the 3rd Annual Conference on Theory and Applications of Models of Computation (TAMC)*, pp. 171-180, (Eds.) Jin-Yi Cai, S. Barry Cooper and Angsheng Li, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 3959, Beijing (China), May 2006.

[C6] K. Subramani. Totally Clairvoyant Scheduling with Relative Timing Constraints. *Proceedings of the 7th International Conference on Verification, Model Checking and Abstract Interpretation (VMCAI)*, pp. 398-411, (Eds.) E. Allen Emerson and Kedar Namjoshi, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 3855, Charleston (South Carolina), January 2006.

4 Refereed Workshop Publications

[W1] Xiaofeng Gu, Kamesh Madduri, K. Subramani and Hong-Jian Lai. Improved algorithms for detecting negative cost cycles in undirected graphs. *Proceedings of the Third International Frontiers of Algorithmics Workshop (FAW)*, pp. 40-50, (Eds.) Xiaotie Deng, John E. Hopcroft and Jinyun Xue, *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 5598, Hefei (China), June 2009.

[W2] K. Subramani. Absorbing Random Walks and the NAE2SAT problem. *Proceedings of the Second Annual International Frontiers of Algorithmics Workshop (FAW)*, pp. 89-100, (Eds.) Franco Preparata, et. al., *Springer-Verlag*, *Lecture Notes in Computer Science*, vol. 5059, Changsha (China), June 2008.

5   Awards (Cumulative)

[A1] Title: Polyhedral Approaches to Selected Problems in Computational Logic.
Positon: **PI**.
Agency: Algorithmic Foundations (AF) Program,
    Computing and Communication Foundations (CCF) Division, NSF.
Award Number: CCF-0827397.
Duration: $02/09 - 01/12$. Amount: $\$300,250$.
Contact: Dr. Richard Beigel $(2/09-$ **present**$)$.

[A2] Visiting Fellowship, CSL, SRI, $5/08 - 8/08$.

[A3] Visiting Fellowship, CSL, SRI, $5/06 - 8/06$.

6   Honoraria (Cumulative)

[H1] Invited Lecture on Rational and Integer Matrix Games at the Department of Computer Science, Emory University, November 16, 2007. Amount: $150.

[H2] Invited Lecture on Negative Cost Cycles at the Department of Operations Research, Naval Postgraduate School, July 12, 2006. Amount: $250.

[H3] Invited Lecture on Chain Programming at the Department of Mathematical Sciences, Carnegie Mellon University, April 13, 2006. Amount: $100.

7   Educational Contributions

Teaching
  Developed a new course in Network Optimization which was offered in Fall 2008
(http://www.csee.wvu.edu/~ksmani/courses/fa08/nopt/nopt.html).

Advising

- Doctoral Students

    – Currently under advisement

    [DA1] Matthew Williamson.

- Master's Students

    – Graduated

    [MA1] Matthew Williamson.
        Thesis: *Optimal algorithms for shortest paths in red-blue graphs.*
        Defense Date: April 2009.
    [MA2] Chris Tauras.
        Thesis: *State Minimization problems in Finite State Automata.*
        Defense Date: March 2007.

Committee Membership

- Doctoral Thesis Committees

  - Graduated

  [DTG1] Andrea Sutyak (April 2007).

  [DTG2] Ju Zhou (April 2007).

  [DTG3] Dejan Desovski (June 2006).